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Assessment of green building policies – A fuzzy impact matrix approach

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ABSTRACT

Green building has achieved a rapid growth as a result of growing public awareness of environmental impacts of the building stock. It is not unusual that governments use policies as a driving force for green building developments. It is well recognized that effective public policies help to overcome barriers to sustainable development. This study proposed a novel approach to evaluate the effectiveness of policies related to green buildings based on the fuzzy impact matrix. This approach was then tested in the Chinese context to assess how effective are those green building policies implemented during the "Eleventh-Five-Year" period. It is found that these green building related policies are heavily environmental sustainability oriented such as building energy efficiency, emission reduction and pollution control. The results showed that some of these policies are effective for promoting green building development in China. However more efforts are required to improve the policy effectiveness on a range of issues such as the fiscal incentive mechanisms; the transformation to integration design model; the development of energy management contracting market; the enhancement of regulatory control during the demolition stage; and increasing the service life of buildings. These findings provide a useful reference to the future policy making process.

Contents

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1. Introduction

It is well recognized that buildings have significant impacts on the environment. These impacts reflected in consumption of natural resources (e.g. water, energy and materials), production of greenhouse gas emissions, and pollutions (e.g. construction and demolition waste; wast water) [1–4]. For instance, the existing building stock accounts for 30% of total energy consumption [5] and contributes towards 25% of greenhouse gas emission of China [6]. The annual production of waste from construction activities reached 300 million tonnes in China, which accounts for 40% of the total amount of waste volume across the country [7]. The International Energy Agency predicted that the volume of the residential and commercial sector will increase 67% and 195% respectively by 2050 [8]. This makes the environmental impacts of the building stock even more significant. Indeed, the building sector plays a crucial role in achieving sustainable future as documented in the *Vision 2050*, the strategic document of the World Business Council for Sustainable Development [9]. Furthermore, these environmental impacts exist not only during the construction phase, but also the operation phase therefore a life cycle perspective is required to deal with cost and benefit analysis of incorporating sustainability principles into building developments [10–14]. These include the emerging concept of embodied energy of building materials compared to operational energy [15–18].

As a result, the concept of green building was put forward to mitigate these environmental issues. Green building is defined by the US Green Building Council as: "…(buildings that) are designed, constructed, and operated to boost environmental, economic, health, and productivity performance over that of conventional building" [19] (p.4). Kibert further defined green buildings as "…healthy facilities designed and built in a resource-efficient manner, using ecologically based principles" [20] (p.9). Since then the green building has achieved rapid development, as evidenced by the steady growing number of buildings that have been certified by various assessment tools. For instance, more than 13,000 buildings have achieved Leadership in Energy and Environmental Design (LEED) certification from the US Green Building Council by the end of 2012 globally with a total floor area of 709.6 million m^2 [21]. The main benefits associated with green buildings include: long term savings from energy efficiency; reducing resource consumption and waste generation; and health and productivity of tenants due to improved indoor environmental quality [22–24].

Public policy plays a paramount role in facilitating sustainable development, e.g. the structure of power generation; performance of wind turbine manufacturers; air quality issues associated with rapid urbanization; the implementation of corporate social responsibility; and development of sustainable community [25–31]. Similarly, the effective endorsement of public policy plays a crucial role for successful green building developments [32].

The aim of this research is to develop a novel method to evaluate the effectiveness of public policies related to green buildings. This method is then tested in the Chinese context to evaluate how effective are those green building policies released during the 11th Five-Year Plan (2006–2010). The contributions of this study are: (1) serving as the key inputs for authorities for the future policy making related to green buildings and (2) providing a useful reference to the assessment of public policy related to green buildings that may be applicable in other contexts.

2. Research methodology

2.1. Conceptual framework

The policy formulation for green building is also a process of goal management. Therefore it is necessary to clearly define the goals of policy, and then to set the corresponding measures against these goals. Based on this logic, this paper provides a methodology of a conversion matrix through the establishment of the goals–measures conversion matrix in order to define the green building policy system (see Fig. 1). The row vector represents policy goals and the column vector represents policy measures against these goals. The elements in the matrix represent the relationship between the goals and policies. This correlation reflects the effectiveness of policies for the realization of goals. Another key issue is to determine the weight and order of policy measures based on the weight of policy goals. This order reflects the priorities of policies for realizing the specific goals.

Therefore, the steps of the policy system based on the goals–measures matrix are:

1. Identifying the policy goals.
2. Formulating corresponding policies.
3. Determining the order for the formulated policies according to the objectives–measures matrix (i.e. the policy with the higher order is more significant for the realization of the specific goal).

As shown in Fig. 2, the first stage of this research involves critical review of relevant literature on green building in China, particularly barriers and policies. A policy assessment framework will be developed based on fuzzy impact matrix. Consequently, relative importance and priority of policy measures will be identified. This is followed by the evaluation of green building related pubic policies in China that were released during the 11th Five Year Plan period (2006–2010). The results aim at providing a useful reference to the future policy making.

2.2. Policy assessment method based on the fuzzy conversion matrix

2.2.1. Methodology selection

Policy evaluation needs a combination of the value analysis and empirical analysis. The fuzzy evaluation method is adopted in this study to establish the green building policy evaluation model. The fuzzy set theory is an effective method for multi-objective optimization problems with a consideration of some degree of subjective imprecision of decision makers [33,34]. In other words, fuzzy theory provides a connection between the subjective judgment and objective analysis. On one hand, the value judgment of policy measures is conducted the fuzzy scoring process. On the other hand, the mathematical analysis is presented via establishing a fuzzy evaluation model.

A triangular fuzzy number is adopted to establish the policy evaluation model. Triangular fuzzy number has been widely used

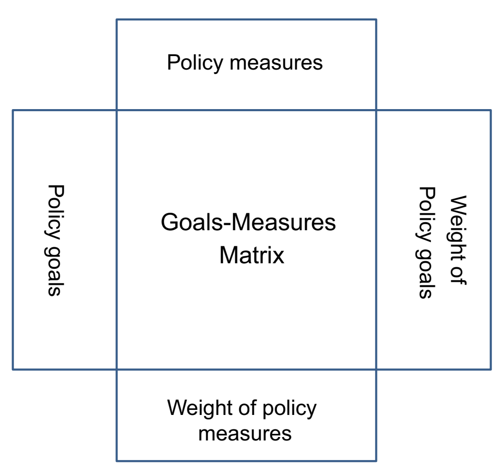

Fig. 1. Goals-measures matrix.

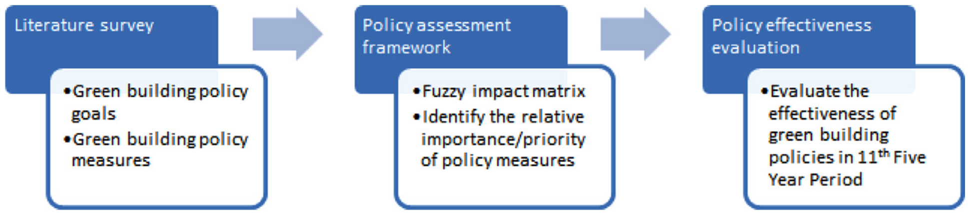

Fig. 2. Research process.

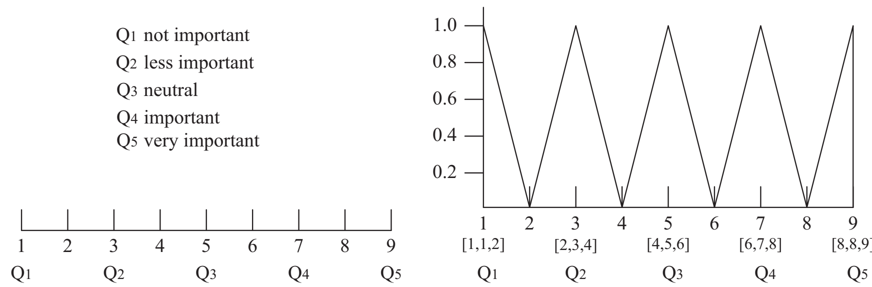

Fig. 3. Scoring mechanism and triangular fuzzy number.

because of its simple calculation and easy understanding [35–37]. It is described as below:

Hypothesis. A is a fuzzy subset in domain of R, x is an element in A and its membership function is:

$$\mu_A(x) = \begin{cases} (x-a)/(b-a), & a \le x \le b \\ (c-x)/(c-b), & b \le x \le c \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

a fuzzy number $A=(a,b,c)$ is said to be a triangular fuzzy number a, c is defined as the lower limit and upper limit of triangular fuzzy numbers respectively, b is the maximum value with the highest possibility rate (when $x=b$, $\mu_A(x)=1$).

We adopted the approach proposed by Kuo et al. [44] and Li [45] to establish the evaluation model for green building policies according to the goals–measures conversion matrix [38,39]. These are described in the next section.

2.2.2. *The importance of policy ranking and evaluation method based on the fuzzy transformation matrix*

According to matrix transformation model described in Fig. 3, the weight determination of the policy system can be divided into the following steps: (1) establish the policy goals of green building; (2) determine the weight of the policy goals; (3) set the specific policy measures against the goals; (4) establish goals–measures correlation matrix and (5) calculate the weight of each policy according to the correlation matrix.

The key of above steps is the identification of the weights of policy goals and the formation of the goals–measures correlation matrix. We propose the following procedure:

(1) Weight of policy goals: score the weight of the policy goals through the Expert Grading Method (EGM) with a score ranging from 1 to 9 at 5 levels. 1,3,5,7,9 represents not important, less important,, neutral, important and very important respectively. Then the triangular fuzzy number theory is applied to calculate the score of each policy goal graded by the experts. This is followed by the calculation of the average fuzzy weight graded by P experts for item I policy goal. Consequently, the final fuzzy average weight to policy item I is obtained.
Assume there are P experts that assign weight to N policy measures, the qth expert's weighting matrix is:

$$w^q = (w_1^q,\ w_2^q, \ldots, w_n^q)^T$$

where w_i^q is the original weight;
The corresponding fuzzy matrix is:

$$\delta^q = (\delta_1^q,\ \delta_2^q, \ldots, \delta_n^q)^T \tag{2}$$

where δ_i^q is the corresponding triangular fuzzy number of w_i^q.
The conversion process of triangular fuzzy numbers is shown in Fig. 3.
In general, δ_i^q can be expressed as:

$$(L\delta_i^q, M\delta_i^q, U\delta_i^q)$$

where $L\delta_i^q$, $M\delta_i^q$, and $U\delta_i^q$ denotes the lower limit, middle value and upper limit of δ_i^q respectively. This corresponds to $A=(a,b,c)$ in the definition of triangular fuzzy number. For instance, the qth expert assigned the weight of ith policy measure as: $w_i^q=7$. According to the above equations, the corresponding triangular fuzzy number is: $\delta_i^q=(6,\ 7,\ 8)$. In addition, when w_i^q is 1 and 9, the corresponding δ_i^q is (1, 1, 2) and (8, 9, 9) respectively. Consequently, the final fuzzy weight of ith policy measure is obtained by calculating the average of fuzzy weight of all P experts on this policy measure:

$$\delta_i = (L\delta_i, M\delta_i,\ U\delta_i) = \left(\frac{1}{p}\sum_{q-1}^{p} L\delta_i^q,\ \frac{1}{p}\sum_{q-1}^{p} M\delta_i^q,\ \frac{1}{p}\sum_{q-1}^{p} U\delta_i^q \right) \tag{3}$$

(2) Goal–measures correlation matrix: this is similar to the process of determination of weight of policy goals, i.e. via expert grading process. 1,3,5,7,9 represents not related at all, not related, neutral, related, very related respectively. The triangular fuzzy number theory is applied to calculate the score of correlation between each pair of policy goals and measures graded by the experts.

(3) Policy measure priority and weight: once the goals–measures correlation matrix is determined according to the rule of matrix multiplication and triangular fuzzy number multiplication, we can calculate E_i^j:

$$E_i^j = S_i^j \otimes \delta_i. \tag{4}$$

where S_i^j is the score of the fuzzy correlation between policy goal I and policy measure j, δ_i is the fuzzy average weight of policy goals of item i. During this process, E_i^j is the fuzzy matrix. This is followed by a process of defuzzification applying the center of

gravity method [40], i.e. converting the triangular fuzzy number back to value u_i^j.

Hypothesis. $A_i^j(x)$ is a membership degree function of triangular fuzzy number e_i^j between column I and row j in matrix E_i^j, then the value after the defuzzification to the of triangular fuzzy number e_i^j is:

$$u_i^j = \frac{\int_x^b x \cdot A_i^j(x)dx}{\int_x^a A_i^j(x)dx} \tag{5}$$

where a and b are the lower limit and upper limit of triangular fuzzy number e_i^j respectively,then use

$$w_j = \frac{\sum_i u_i^j}{\sum_j \sum_i u_i^j} \tag{6}$$

to normalize the policy measures' value u_i^j. As a result, the related weight for each policy measure is determined.

2.2.3. Method to evaluate policy effectiveness

The intuitionistic fuzzy sets are employed to evaluate the policy of green building during the period of the “Eleventh Five-Year” in China.

For the normal fuzzy set A, the degree of membership $\mu_A(x)$ of element x is a value between 0 and 1, while this value assumed that the degree of non-membership for element x is $1-\mu_A(x)$. However, in practice, the degree of non-membership does not absolutely equal to 1 minus the degree of non-membership.,It is often less than $1-\mu_A(x)$, because it has one uncertain space of hesitation, i.e. uncertain probabilistic space. Atanassov [47] expanded the original fuzzy set theory and proposed a new concept named “Intuitionistic Fuzzy Sets” by introducing a hesitation degree between the degree of membership and the degree of non-membership [41].

Definition. Assume X is a certain set, the intuitionistic fuzzy sets A in Set X can be described as below: $A = \{ < x, \mu_A(x), \nu_A(x) > | x \in X\}$, $\mu_A(x) : X \to [0,1]$, $\nu_A(x) : X \to [0,1]$, and meet $0 \le \mu_A(x) + \nu_A(x) \le 1, x \in X$, then said $\mu_A(x)$ is the degree of membership of element $x(\in X)$ to set A, $\nu_A(x)$ is the degree of non-membership of element $x(\in X)$ to set A; $\pi_A(x) = 1-\mu_A(x)-\nu_A(x)$ is the degree of hesitation of $x(\in X)$ to set A. for any $x \in X$, $0 \le \pi_A(x) \le 1$, when the intuitionistic fuzzy sets degenerate to normal fuzzy sets, $\pi_A(x) = 0_o$.

3. Green building policy goals and measures

According to China's Green Building Evaluation Standard (BG/T50378-2006), the main functions of green buildings include conservation of natural resources (e.g. energy, land, water and material); environmental protection; pollution reduction; and providing a health and comfortable environment to users. In essence, green building focuses on a natural harmonious coexistence between human being and built environment across various life cycle stages of building. Green building is not only related to the construction industry itself but also affects the other sectors and broader environment. Green buildings involve the market demand side, namely buyers and users whose demands on the performance of buildings is growing constantly. Therefore, the attention to these demands becomes one of important aspects for the government to guarantee the people’s quality of life and harmonious society development.

The challenges for implementing green buildings in China are well documented in prior studies. Geng and Doberstein [33] asserted that the barriers to green building development, as part of circular economy policy generally fell into three categories, i.e. technology (e.g. lack of revolutionary science and technology developments to assist achieving green building goals), policy (e.g. fragmented regulation system prevented green building innovations) and public participation (e.g. lack of resources for educating public on sustainability issues) [42]. A study commissioned by the Centre for Housing Centralization of China suggested that major barriers for green buildings in China are: public awareness, institutional factors, technological factor and high upfront cost [43,44]. This is reinforced in Zhang et al. [36]'s study which found that higher cost presents one of the most significant barriers to the green housing developments in China [45]. Similarly, the willingness of customers to accept and pay for green features is also crucial. Zhang et al. [37] also suggested “interests conflicts between various stakeholders” may hinder the effective implementation of green estate developments [46]. Therefore, it is imperative to maintain communication and cooperation between stakeholders [47].

Therefore the goals of green building policies are:

- To provide economic incentives to stimulate green building developments (G1).
- To provide a sound legal system which provides a unified platform to encourage and supervise green building development (G2).
- To provide sophisticated and robust technical standards to guide green building developments (G3).
- To enhance public's awareness and knowledge of green buildings (G4).
- To encourage novel delivery and management approaches for green building developments by means of integration and engagement of various stakeholders (G5); and
- To educate consumers in order to improve their willingness to accept and willingness to pay for improving building performance (G6).

The green building related policies released by authorities such as Ministry of Finance (MoF), Ministry of Housing and Urban-rural Development (MoHURD), Ministry of Science and Technology (MoST) and National Development and Reform Commission (NDRC) are reviewed such as:

- Evaluation standard for green building (GB/T 50378-2006), June 2006.
- Technical guidelines for green building evaluation, August 2007.

Table 1
The policy measures promoting green building during the development decision stage.

P1	Improve the legal system to strictly control the project approval procedure for building energy efficiency
P2	Set up the economic incentives (e.g. the positive incentive such as tax cut or subsidies and the negative incentives such as pollution tax)
P3	Continuously promote demonstration projects and establish long-term and centralized demonstration bases
P4	Encourage the green building development from individual building level to the sustainable communities and urban sustainability level. Promote green building in the rural areas according to local conditions
P5	Increase the proportion of affordable housing to the housing stock and incorporate sustainability features into affordable housing

Table2
The policy measures during the material production/supply stage.

P6 Promote the research and development on sustainable materials and equipment
P7 Improve the technical standard system, energy tag system and the certificating system for sustainable material and equipment
P8 Strengthen the supervision and management to roll out outdated technologies and products
P9 Set up incentive measures for manufacturing and supply of sustainable materials and equipment

Table 3
The policy measures during the design and construction stage.

P10 Improve the standard and assessment system for sustainable design and construction. Gradually establish market entry regulations
P11 Strengthen the acceptance evaluation and supervision for the sustainable design and construction
P12 Encourage more training, cooperation and collaboration on sustainable design and construction
P13 Promote the integrated design and professional development of consultants
P14 Encourage innovations on construction management innovation (e.g. turn-key decoration or industrialization, etc.)

Table 4
Policy measures during the operation stage.

P15 Establish the energy consumption supervision system for the public buildings (e.g. monitoring, auditing, bulletin and quota management)
P16 Make it mandate for the developers to release the sustainability related data and maintenance guarantee, and to monitor the operational performance of the building
P17 Promote the energy management contracting through energy service companies, facility and asset management consultancies and industry associations
P18 Provide economic incentives to the consumers of the sustainable buildings and/or products
P19 Gradually retrofit existing buildings and provide users preferential policies
P20 Education to enhance the sustainable consumption and living style of the public

Table 5
Policy measures during the demolition stage.

P21 Increase the life of buildings and avoid unnecessary demolition
P22 Encourage the research and development of the recycling or renewable technologies. Develop related technical standards
P23 Set up the economic incentive policies, and cultivate the reuse and recycling market for the construction and demolition waste
P24 Strengthen the supervision of the demolition to reduce the pollution and waste

- Management measures for green building evaluation and labeling, August 2007.
- Implementation scheme for demonstrated application of renewable energy in buildings in cities, July 2009.
- Notice of Ministry of Finance and Ministry of Housing and Urban-rural Development on Further Promoting Application of Renewable Energy in Buildings, March 2011.
- The implementation opinion on Accelerating the Promotion of Green Building Developments, April 2012.
- Special plan for technological developments to deal with climate change during the Twelfth Five Year period, May 2012.
- The Building Energy Efficiency Strategic Plan for the Twelfth Five-Year period, May 2012;
- Notice on improving the policies relevant to renewable energy application in buildings and mechanisms for funds allocation, August 2012; and
- Green Building Action Plan, January 2013.

A critical analysis was conducted to these official documents. The aim of this critical analysis is to highlight the policy measures related to green building development at each stage of project life cycle, i.e. decision development, material supply, building design and construction, operation & maintenance, and demolished or recycle stages (see Tables 1–5).

As shown in Tables 1–5, the life cycle based green building policy system consists of five stages and 24 policy measures. These provide key inputs for the priority assessment for the policy measures based on the goals–measures matrix of green building as shown in Fig. 1.

Table 6
Scoring example.

(8, 9, 9)	(6, 7, 8)	(8, 9, 9)	(8, 9, 9)	(8, 9, 9)
(8, 9, 9)	(6, 7, 8)	(6, 7, 8)	(8, 9, 9)	(8, 9, 9)
(6, 7, 8)	(8, 9, 9)	(6, 7, 8)	(6, 7, 8)	(8, 9, 9)
(6, 7, 8)	(6, 7, 8)	(6, 7, 8)	(6, 7, 8)	(8, 9, 9)

4. Case study: the assessment and effectiveness analysis of green building related policies during the “Eleventh-Five-Year” in China

The “Eleventh Five-Year” is a critical period in China for the development of green building. Green buildings are widely applied across the nation. According to the assessment method described in the research methodology section, green building policies released during the “Eleventh-Five-Year” in China are evaluated.

4.1. *Priorities of green building policy*

This research was undertaken in Shanghai, one of the most developed regions in China. The massive construction market has created significant demand on green buildings. A total of 20 experts were invited to participate into this study. These experts are experienced on green building developments. Each expert held a senior position in their organizations, e.g. government authorities, design institutes, contractors and supervision engineers. Their titles range from chief engineer, chief architect, chief supervision engineer to director.

Table 7
Goal–measure correlation at the developmental decision stage.

Goal\measure	P1	P2	P3	P4	P5
G1	(4.4, 5.4, 6.4)	(4.6, 5.6, 6.6)	(6.4, 7.1, 8.1)	(6.2, 7.2, 8.1)	(2.8, 3.8, 4.8)
G2	(2.2, 3.0, 4.0)	(7.6, 8.6, 8.8)	(2.15,3.1, 4.1)	(3.6, 4.6, 5.6)	(3.2, 4.2, 5.2)
G3	(4.4, 5.4, 6.4)	(5.0, 6.0 7.0)	(6.2, 7.2, 8.0)	(6.1, 7.1,7.95)	(4.8, 5.8, 6.8)
G4	(7.4, 8.4, 8.7)	(2.3, 3.2, 4.2)	(2.35,3.3, 4.3)	(3.8, 4.8, 5.8)	(5.6, 6.6, 7.5)
G5	(3.6, 4.6, 5.6)	(4.8, 5.8, 6.8)	(4.2, 5.2, 6.2)	(4.4, 5.4, 6.4)	(2.7, 3.6, 4.6)
G6	(5.3, 6.2, 7.2)	(5.2, 6.2, 7.1)	(4.4, 5.4, 6.4)	(4.6, 5.6, 6.6)	(8.0,8.5, 8.75)

Table 8
Goal–measure correlation at the material production/supply stage.

Goal\measure	P6	P7	P8	P9
G1	(6.5, 7.5, 8.25)	(6.5, 7.5, 8.25)	(4.8, 5.8, 6.8)	(4.4, 5.4, 6.4)
G2	(2.3, 3.2, 4.2)	(2.1, 3.0, 4.0)	(2.3, 3.2, 4.2)	(7.2, 8.2, 8.6)
G3	(5.6, 6.6, 7.6)	(5.2, 6.2, 7.2)	(4.4, 5.4, 6.4)	(4.6, 5.6, 6.6)
G4	(4.6, 5.6, 6.6)	(5.2, 6.2, 7.2)	(7.3, 8.3, 8.65)	(2.3, 3.2, 4.2)
G5	(3.4, 4.4, 5.4)	(3.4, 4.4, 5.4)	(4.6, 5.6, 6.6)	(4.2, 5.2, 6.2)
G6	(4.8, 5.8, 6.8)	(5.6, 6.6, 7.6)	(5.2, 6.2, 7.2)	(5.1, 6.1, 7.1)

Table 9
Goal–measure correlation at the design and construction stage.

Goal\measure	P10	P11	P12	P13	P14
G1	(7.2, 8.2, 8.6)	(4.4, 5.4, 6.4)	(6.2, 7.2, 8.1)	(5.6, 6.6, 7.6)	(5.2, 6.2, 7.2)
G2	(2.3, 3.2, 4.2)	(2.1, 3.0, 4.0)	(2.3, 3.2, 4.2)	(2.2, 3.1, 4.1)	(2.2, 3.0, 4.0)
G3	(5.4, 6.4, 7.4)	(4.5, 5.5, 6.5)	(7.0, 8.0, 8.5)	(6.2, 7.2, 8.1)	(5.6, 6.6, 7.6)
G4	(5.2, 6.2, 7.2)	(7.4, 8.4, 8.7)	(2.5, 3.4, 4,4)	(2.8, 3.8, 4.8)	(3.2, 4.2, 5.2)
G5	(3.2, 4.2, 5.2)	(4.6, 5.6, 7.6)	(5.6, 6.6, 7.5)	(7.4, 8.4, 8.7)	(7.1,8.1, 8.55)
G6	(6.3, 6.5, 7.5)	(5.4, 6.4, 7.4)	(4.8, 5.8, 6.8)	(5.2, 6.2, 7.2)	(5.0, 6.0, 7.0)

4.1.1. *Weight of policy goals*

These experts were asked to grade the score for the weight of policy goals. The mean value is calculated according to the process described in Eq. (2) in the research methodology section. The average weight of the six policy goals are: G1 (6.80, 7.80, 8.40); G2 (7.00, 8.00, 8.50); G3 (6.30, 7.30, 8.05); G4 (6.90,7.90,8.4); G5 (6.10, 7.10, 7.95); G6 (6.30, 7.30, 8.10).

For instance, the scores assigned by 20 experts to the G2 policy goal are (see Table 6):

According to Eq. (2), the average weight of G2 is (7.00, 8.00, 8.50).

The order of these six policy goals in terms of weighted priority is: G1,G2, G3, G6, G4, and G5. This indicated that experts collectively assigned higher priority to the goals of economic incentive, regulation, related technologies and attention to consumers' demands for green building policies.

4.1.2. *Goal–measure correlation Matrix*

Based on the scores assigned by experts and Eq. (3), Goal–measure correlation matrix is obtained (see Tables 7–11).

4.1.3. *Policy priority*

The weights of policy measures are determined based on Eqs. (4)–(6). The policy measures are ranked according to the accumulated weights. The top ranked 12 policy measures and their priorities are shown in Table 12.

Key findings from Table 12 are:

(1) More attention of green building is placed on design stage, construction stage and operation and maintenance stage. This is due to the significant impacts of these stages on both the building itself and the environment. By contrast, there is comparatively little attention to the recycling and demolition stage.
(2) During the development decision stage, the key emphasis is placed on providing fiscal incentives and to expand the scale of green buildings with aims to inspire the enthusiasm of market participants.
(3) Similar to the design and construction stage, the policy measures during the material production and supply stage mainly focused on improving the technical standards and supervision policy.
(4) During the operation and maintenance stage, the top priority is placed on the building retrofitting as a large proportion of existing buildings are not green buildings. The second priority focused on the innovation of the micro-management, e.g. developing the market of operating green buildings via energy management contracting approach. The third priority is the regulatory control of the public buildings. The public awareness of energy conservation has improved significantly however many public buildings consume exceptional amount of energy. Therefore, green building policies should focus on the strict supervision of sustainable performance of public buildings.
(5) During the recycling and demolition stage, efforts are required to strengthen the supervision, and prevention of pollution and waste. It is another crucial policy to extend the life of buildings. At the moment, the average life of buildings in China is about 30–35 years, which is significant less than the standard building life of 50 years. It is an effective measure on energy conservation and environmental protection by means of reducing the frequency of building demolition.
(6) The regulatory supervision plays a critical role in all five stages of a building life cycle (see Table 12). However, it is worth noting that the supervision policy may not be the best

Table 10
Goal–measure correlation at the operation and maintenance stage.

Goal\measure	P15	P16	P17	P18	P19	P20
G1	(4.6,5.6,6.6)	(4.4,5.4,6.4)	(4.2,5.2,6.2)	(4.6,5.6,6.6)	(5.4,6.4,7.4)	(4.4,5.4,6.4)
G2	(2.3,3.2,4,2)	(2.2,3.0,4.0)	(3.0,4.0,5.0)	(7.5,8.5,8.75)	(5.2,6.2,7.2)	(2.6,3.6,4.6)
G3	(5.2,6.2,7.2)	(5.2,6,2,7,2)	(5.2,6.2,7.2)	(5.2,6.2,7.2)	(4.8,5.8,6.8)	(7.5,8.5,8.75)
G4	(7.2,8.2,8.6)	(7.0,8.0,8.5)	(3.2,4.2,5.2)	(2.2,3.0,4.0)	(3.2,4.2,5.2)	(3.8,4.8,5.8)
G5	(4.8,5.8,6.8)	(3.6,4.6,5.6)	(7.2,8.2,8.6)	(3.6,4.6,5.6)	(4.2,5.2,6.2)	(4.6,5.6,6.6)
G6	(4.4,5.4,6.4)	(5.4,6.4,7.4)	(5.4,6.4,7.4)	(3.2,4.2,5.2)	(6.5,7.5,8.25)	(5.2,6.2,7.2)

Table 11
Goal–measure correlation at the demolition stage.

Goal\measure	P21	P22	P23	P24
G1	(5.2, 6.2, 7.2)	(7.2, 8.2, 8.6)	(4.6, 5.6, 6.6)	(4.4, 5.4, 6.4)
G2	(2.8, 3.8, 4.8)	(2.4, 3.4, 4.4)	(7.4, 8.4, 8.7)	(2.3, 3.2, 4.2)
G3	(5.0, 6.0, 7.0)	(4.8, 5.8, 6.8)	(5.4, 6.4, 7.4)	(4.8, 5.8, 6.8)
G4	(5.1, 6.1, 7.1)	(5.2, 6.2, 7.2)	(2.3, 3.2, 4.2)	(7.4, 8.4, 8.7)
G5	(4.6, 5.6, 6.6)	(2.8, 3.8, 4.8)	(3.8, 4.8, 5.8)	(4.2, 5.2, 6.2)
G6	(5.2, 6.2, 7.2)	(4.6, 5.6, 6.6)	(4.4, 5.4, 6.4)	(5.1, 6.1, 7.1)

Table 12
Priority of policy measures from project life-cycle perspective.

Policy description	Accumulated weight	Standard weight	Priority
P19 Gradually retrofit existing buildings and provide users preferential policies	265.538	0.08519	1
P2 Set up the economic incentives (e.g. the positive incentive such as tax cut or subsidies and the negative incentives such as pollution tax)	265.11	0.08505	2
P10 Improve the standard and assessment system for sustainable design and construction. Gradually establish market entry regulations	262.26	0.08413	3
P13 Promote the integrated design and professional development of consultants	261.74	0.08397	4
P4 Encourage the green building development from individual building level to the sustainable communities and urban sustainability level. Promote green building in the rural areas according to local conditions	260.819	0.08367	5
P11 Strengthen the acceptance evaluation and supervision for the sustainable design and construction	259.582	0.08327	6
P17 Promote the energy management contracting through energy service companies, facility and asset management consultancies and industry associations	258.97	0.08308	7
P8 Strengthen the supervision and management to roll out outdated technologies and products	258.763	0.08301	8
P15 Establish the energy consumption supervision system for the public buildings (e.g. monitoring, auditing, bulletin and quota management)	257.993	0.08276	9
P24 Strengthen the supervision of the demolition to reduce the pollution and waste	255.673	0.08202	10
P21 Increase the life of buildings and avoid unnecessary demolition	255.433	0.08194	11
P7 Improve the technical standard system, energy tag system and the certificating system for sustainable material and equipment	255.317	0.08191	12
Total	3117.198	1.0000	

approach for green building developments as it may introduce barriers to the free market. The sustainable development of green buildings should be a result of market competition, rather than merely through the mandatory requirements of the laws and regulations. This is clearly shown in Table 12. The policy measures that are ranked higher than regulatory policy are on market, technology and micro-management such as: the fiscal incentives for development decision stage, the improvement of technical standards and evaluation system, and transforming to the integrated design model. Both the building retrofitting policy and policy of expansion the scale of green building can be regarded as opportunities for the future market development. If the government can cultivate the market under this background, there is a prosperous future of green building in China.

4.2. Evaluation of policy effectiveness and discussion

In the previous section, 12 policies relatively more important for implementing green building were identified. However, the effectiveness of these green building related policies during the "Eleventh-Five-Year" remained unanswered. The evaluation of the policy effectiveness is discussed in this section.

We adopted the intuitionistic fuzzy sets to evaluate the policy of green building during the period of the "Eleventh Five-Year" in China. The same group of experts was invited to make an intuitionistic fuzzy judgment to the 12 relatively important policy items shown in Table 12, which are listed according to the order of project life-cycle. All experts were required to fill in a questionnaire after the researchers provided a detailed explanation. For each policy measure, experts were asked to provide his/her judgment of the degree of recognizing and non- recognizing the effectiveness of the policy implemented during the "Eleventh Five-Year" period. The sum of these two values should be less or equal to 1.

Based on these 20 questionnaires, the average value of recognizing degree $\overline{\mu_i}(x)$ and the non- recognizing degree $\overline{\nu_i}(x)$ to each of the policy item are calculated. Consequently the average value of hesitation $\overline{\pi_i}(x) = 1 - \overline{\mu_i}(x) - \overline{\nu_i}(x)$ are determined. There three values are the degree of membership, the degree of non-membership and the hesitation degree to each policy item.

In order to provide intuitive outputs, we assign values for the judgment process:

- The degree of membership is assigned 5 points if the experts recognized "this policy has been fully implemented with effective outcomes during the 'Eleventh Five-Year' period".
- The degree of non-membership is assigned 1 point if the experts did not recognize "this policy has been fully implemented with effective outcomes during the 'Eleventh Five-Year' period".
- For uncertain judgments, the hesitation degree is assigned 3 points.

Then the evaluation score for each policy measure is:

$$S_i = \overline{\mu_A}(x) \times 5 + \overline{\pi_A}(x) \times 3 + \overline{\nu_A}(x) \times 1 \quad (7)$$

Based on Eq. (7), the score of each policy measure is calculated and shown in Table 13.

Based on the score and weight of each policy measure, the total comprehensive score of the green building policy system during the period of "Eleventh Five-Year" is calculated as below:

$$\text{Total Score} = \sum_i S_i \times \omega_i = (3.12 \times 0.08505 + 3.6 \times 0.08367 + \ldots + 3.32 \times 0.08202) \approx 3.54 \quad (8)$$

Using this threshold value, half of these green building policies are effective during the period of "Eleventh Five-Year". This indicates more efforts are required to improve the policy framework despite a number of green building policies in place and notable achievements. green building policies implemented As shown in Table 12, the most effective green building policy is "Establish the energy consumption supervision system for the public buildings, e.g. monitoring, auditing, bulletin and quota management" (P15), followed by "Gradually retrofit existing buildings and provide users preferential policies" (P19). Both policies focus on the operation and maintenance stage of green building development. This clearly indicates the policies have placed focus on the operation and real performance of building, especially the energy efficiency. Green building development is normally associated with high capital cost. Therefore, better energy efficiency and building performance help to justify the investment on green features. It is recognized that existing building stock plays a crucial role to achieve sustainable development goal. As a result, it is imperative to have policies and incentives in place to encourage retrofitting existing buildings with lower performance level. According to experts, both policies are very effective to promote green building development during the "Eleventh-Five-Year". These policies could be further reinforced in future policies.

It is also worth noting that that "Set up the economic incentives (e.g. the positive incentive such as tax cut or subsidies and the negative incentives such as pollution tax)" (P2) and "Promote the integrated design and professional development of consultants" (P13) is not effective to promote green building developments during the period of "Eleventh Five-Year" compared to other policies. In contrast, the priority of these two policies is 2nd and 4th respectively. This indicates that both policies are "short legs" of the policy system and have not achieved the goals of promoting green buildings, even though priorities should be given on economic incentives and promotion of integrated design. These policies need to be revisited where inputs should be sought from both the industry and academic. More specifically, sufficient and effective measures that enhance these two policies need to be put forward by the government. Indeed, stakeholder engagement is a critical component of policy making process. Specific goals and implementation measures will help to improve the effectiveness of policies. For instance, one of experts made a comment that P2 policy will be more effective if a clear guideline is provided in terms of when and how much incentive will be provided by the government for those building developments achieving three-star green label.

Table 13
Fuzzy evaluation of effectiveness of green building policies during the "Eleventh-Five-Year".

Life cycle stages	Policies	Standardized weight ω_i	$\overline{\mu_i}(x)$	$\overline{\pi_i}(x)$	$\overline{\nu_i}(x)$	Score S_i
Developmental decision	P2	0.08505	0.385	0.29	0.325	3.12
	P4	0.08367	0.535	0.23	0.235	3.6
Material production and supply	P7	0.08191	0.58	0.255	0.165	3.83
	P8	0.08301	0.535	0.255	0.21	3.65
Design and construction	P10	0.08413	0.46	0.29	0.25	3.42
	P11	0.08327	0.555	0.23	0.215	3.68
	P13	0.08397	0.37	0.33	0.30	3.14
Operation and maintenance	P15	0.08276	0.67	0.185	0.145	4.05
	P17	0.08308	0.435	0.255	0.31	3.25
	P19	0.08519	0.635	0.22	0.145	3.98
Demolition	P21	0.08194	0.42	0.365	0.215	3.41
	P24	0.08202	0.435	0.29	0.275	3.32

5. Conclusion

This study focused on the evaluation of effectiveness of public policies related to green buildings. A critical literature survey was conducted to identify the relevant policies in Chinese context from a project life cycle perspective. Six policy goals and twenty four policy measures were highlighted. A comprehensive fuzzy evaluation method is proposed to establish policy–measures matrix for further promoting green building developments. This is followed by the priority analysis to the policy system according to the triangular fuzzy number theory and the effectiveness assessment of relevant policies that were implemented during the "Eleventh–Five Year" period based on the priority order in Table 12. The results showed that only half of these policies were considered as effective by experts for promoting green building developments. However, there is room for further improvements such as setting up the related fiscal incentive measures as soon as possible. In addition, it calls for an enhancement on the project management methodology by means of the promotion of the integrated design, construction industrialization and energy management contracting. At the same time, efforts are required to strengthen the administrative supervision of the design and construction stage; to release more detailed technical standards; to reduce unnecessary demolition and to prolong the service life of buildings. Furthermore, it is suggested to consider enhancing the public and knowledge of green building as a long term strategy.

Future research opportunities exist to have in-depth study of the effectiveness of public policies in each project life cycle stage of green buildings. For the evaluation methods, we adopted the triangle fuzzy matrix transformation evaluation method for this paper. Other methods such as the neural network algorithm (NNA), the genetic algorithm, and the TOPSIS algorithm can be considered for policy evaluation as well.

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